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Prepared in cooperation with the Minnesota Pollution Control

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Water-Resources Investigations Report 99-4290

U.S. Department of the Interior
U.S. Geological Survey

Development of a stream habitat index for use with an Index of Biotic Integrity in the St. Croix River Basin, Minnesota

By R.M. Goldstein[1], D.L. Lorenz[1], and Scott Niemela[2]

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CONVERSION FACTORS

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	.6214	mile
square kilometer (km^2)	.3861	square mile

Development of a stream habitat index for use with an Index of Biotic Integrity in the St. Croix River Basin

By Robert M. Goldstein, David L. Lorenz, and Scott Niemela

Abstract

More than 70 streams in the St. Croix River Basin in Minnesota were sampled for fish community composition and physical habitat during 1996–98. A habitat index was developed based on measurements, field observations, and land use. The objective was to develope a habitat index for use to evaluate water quality and the effects of nonpoint-source effects not associated with habitat degradation. Core habitat variables were determined with a concurrence analysis using principal components of two subsets of sites with pristine or least affected habitat. Although core habitat variables differed slightly between data sets, sufficient similarities allowed development of an index. The index (the sum of pluses or minuses dependent on the variable's correlation to biotic integrity), composed of 12 core habitat variables in 5 classification groups (hydrology, geomorphology, substrate, instream habitat, and riparian/land use), was able to distinguish sites with low Index of Biotic Integrity scores not related to habitat degradation.

Introduction

Development of biological criteria (biocriteria) for the evaluation of aquatic resource quality is mandated by the U.S. Environmental Protection Agency (EPA) under the Clean Water Act of 1972 (and its amendments). The most common biocriteria methods involve the use of an Index of Biotic Integrity (IBI) (Karr, 1981). An IBI is a multi-metric evaluation system based on the structure and function of a biological community in the stream. In many cases, the biological community that is evaluated is the fish community. IBIs usually consist of 10 to 15 metrics, which rate various aspects of the fish community investigated relative to a reference community from pristine or least affected streams. Metrics address species composition, trophic composition, abundance, and condition (Karr, 1981; Karr and others, 1986).

Habitat is the principle determinant of the biological potential of a stream, and as such can be used to predict biological conditions, particularly the occurrence and abundance of fish (Gorman and Karr, 1978; Plafkin and others, 1989; and Rankin, 1989). Although fish community analyses have been accomplished with numerous approaches, analytical procedures for habitat data are still relatively new. Approaches to habitat data have involved using habitat indices (Fajen and Wehnes, 1982; Plafkin and others, 1989; Rankin, 1989; Petersen, 1992; and Wang and others, 1998), habitat quantification models (Terrel and others, 1982; Nestler and others, 1989; Baker and Coon, 1997), examination of habitat gradients (Schlosser, 1982; Rahel and Hubert, 1991), or analyses of habitat preference (Rosenzweig, 1981; Nelson and others, 1992). Although habitat assessment protocols have attempted to produce a single number or index that can be used to rate stream habitat (for example, Rankin, 1989; Plafkin and others, 1989; Peterson, 1992), the indicies that have been developed are for the most part subjective and contain metrics identified *a priori* (Stauffer and Goldstein, 1997; Wang and others, 1998).

Habitat data have a significant role in biocriteria development. Because the physical habitat of a stream has a major influence on the presence and abundance of fish, it may overshadow or confound the identification of other factors affecting the biotic integrity of fish communities. Therefore, the quantification of stream habitat is important.

Sources of stress can be physical, chemical, and biological. The use of a habitat evaluation system as an adjunct to an IBI provides a synergy of the information collected. Data are then available on the physical and biological components of the resource. When biocriteria scores are compared with physical habitat quality scores, discrepancies could be attributable to water quality. With the current control of most point-source discharges, the evaluation of habitat quality becomes more important to identify streams affected by nonpoint sources.

An analysis was done to develop a habitat index for streams in the St. Croix River Basin in Minnesota. The index is a tool to evaluate stream-habitat data for use with biocriteria assessment. Ideally, the habitat measures can be used to predict the quality of the fish community (IBI) such that deviations from the expected values will indicate other sources of perturbation.

To develop the index, three primary objectives must be met: (1) Identify the features and variables that best describe physical habitat, which are the core habitat variables; (2) Determine which of the core habitat variables are correlated to fish community composition; and (3) Develop a basin specific index of fish community habitat quality from those variables, which is a single number that can be used in conjunction with IBI scores. The primary objectives may be met by the development of a habitat index that is directly related to fish community composition. The approach consists of determining the core habitat variables most correlated to IBI scores, or if IBI scores have not been developed or confirmed, to species richness. This approach assumes that, in reference-condition streams (streams not subjected to sources of external stress), the fish community composition and abundance are directly related to the quality of the physical habitat. This report describes the development of a habitat index for the St. Croix River Basin in Minnesota.

Habitat Analysis

The goal of the habitat analysis was to reduce the number of habitat variables for use in index development and to identify the core habitat variables that best describe the variability in St.Croix River Basin streams. Habitat data were collected, transformed to fit statistical assumptions, separated into data sets, and analyzed to determine the core variables.

Data Collection

From 1996 through 1998, the Minnesota Pollution Control Agency collected data on fish community composition and stream habitat in the St. Croix River Basin in Minnesota (fig. 1) for development of biocriteria. Streams sampled had drainage areas that ranged in size from less than 2.59 km^2 to greater than 12,950 km^2. Under the EPA site selection guidelines (Whitter and Paulsen, 1992), 49 sampling sites were randomly selected within the basin. The EPA-Environmental Monitoring and Assessment Program (EMAP) site selection process uses a map grid and random selection process. Additionally, another 50 sites were specifically selected to encompass the extremes of habitat conditions. Therefore, the gradient of habitat conditions sampled included practically pristine streams to streams that were fully channelized and devoid of internal features. Sampling occurred during the summer, primarily under low flow conditions to provide comparable data relative to hydrologic conditions and to allow young-of-the-year fish to attain a size whereby they are more readily identified. In conjunction with electrofishing to collect a representative fish community sample, various measurements and determinations were made of the physical habitat of the stream. Habitat quantification generally followed Simonson and others (1995) who developed habitat quantification protocols for similar streams in Wisconsin. The principal deviation from Simonson and others (1995) was the use of 13 to 15 transects rather than transects every two mean channel widths.

Habitat Variables

The habitat variables were classified into five groups (Rankin, 1989; Stauffer and Goldstein, 1997) to facilitate analysis (Appendix, at the back of the report). The groups were: hydrology, geomorphology, instream habitat, substrate, and riparian zone/land use. Data were collected at one of three levels of scale (Frissel and others, 1986)—basin, segment, or reach—depending on the variable. Within a reach, all transect data were summarized for each site. Where applicable, the number of transects was normalized to 13. The total number of habitat variables by classification group were: hydrology =4, geomorphology =10, instream habitat =13, substrate =11, and riparian zone/land use =11 (table 1).

Variable Abbreviations and Transformations

Table 1 lists the variables and the abbreviations used in this analysis. Included are the transformations that were used to normalize the data. Many variables could not be used because they had many (more than 20 percent) ties, zeros, or 100 percent values, and therefore could not be transformed to approach a normal distribution for statistical analysis. For example, the variable bends per length of stream was deleted due to too many zeros. The zero value indicates no bends occurred in the reach. Although some of the deleted variables may have contributed to the index, the lack of normality precluded their use.

Transformations of data were based largely on power series. Normality was confirmed with a Shapiro-Wilk test. For negatively skewed data, successive transformations of sqrt(x), sqrt(sqrt(x)), ln(x), -1/sqrt(x), and -1/x were taken to find an acceptable transformation to a normal distribution (sqrt is the square root and ln is the natural logarithm). The variable gradient was an exception where the transformation ln(sqrt(x)) was used.

The final count of normal variables for analysis was 25. Each of the major classification groups (hydrology, geomorphology, etc.) was represented. The basin land use variables were not used because they correlated highly (r=0.96) with the 100 meter land use data.

Data sets

Initially, sites were designated as either “model” or “test” in terms of habitat quality. The “model” habitat sites were reference areas, characterized generally by undeveloped land use and no known discharges. Most model sites contained unaffected habitat. Some sites with relatively poor habitat but no other sources of perturbation were added to this group so that a range of habitat conditions was included. The criteria for inclusion as a model habitat site were:

1. IBI score—for moderate and large streams (drainage area greater than 259 km^2) a score of about 45 or more but in smaller streams, a score greater than 35.

Species Richness—stream scored in the top one-third trisection of the species richness metric.

Riparian corridor—contains native trees and vegetation from 0 to 30 meters away from the stream. The corridor is mostly undisturbed.

Stream geomorphology—stream channel and banks are natural without riprap; stream has not been ditched, channelized, or snagged.

Dams—no dams or impoundments within 5 km of the site.

Point sources—none.

Next, the model sites were divided into two groups, one for index development and the other for verification. A simple coin toss was used to randomly select sites for one group or the other. A third data set (the “test” sites used for testing) included the non-reference sites with lower IBI scores so that the index could be tested in less-than-ideal environmental conditions. This third group was not included in either index development or verification because the lower IBI score could be attributed to

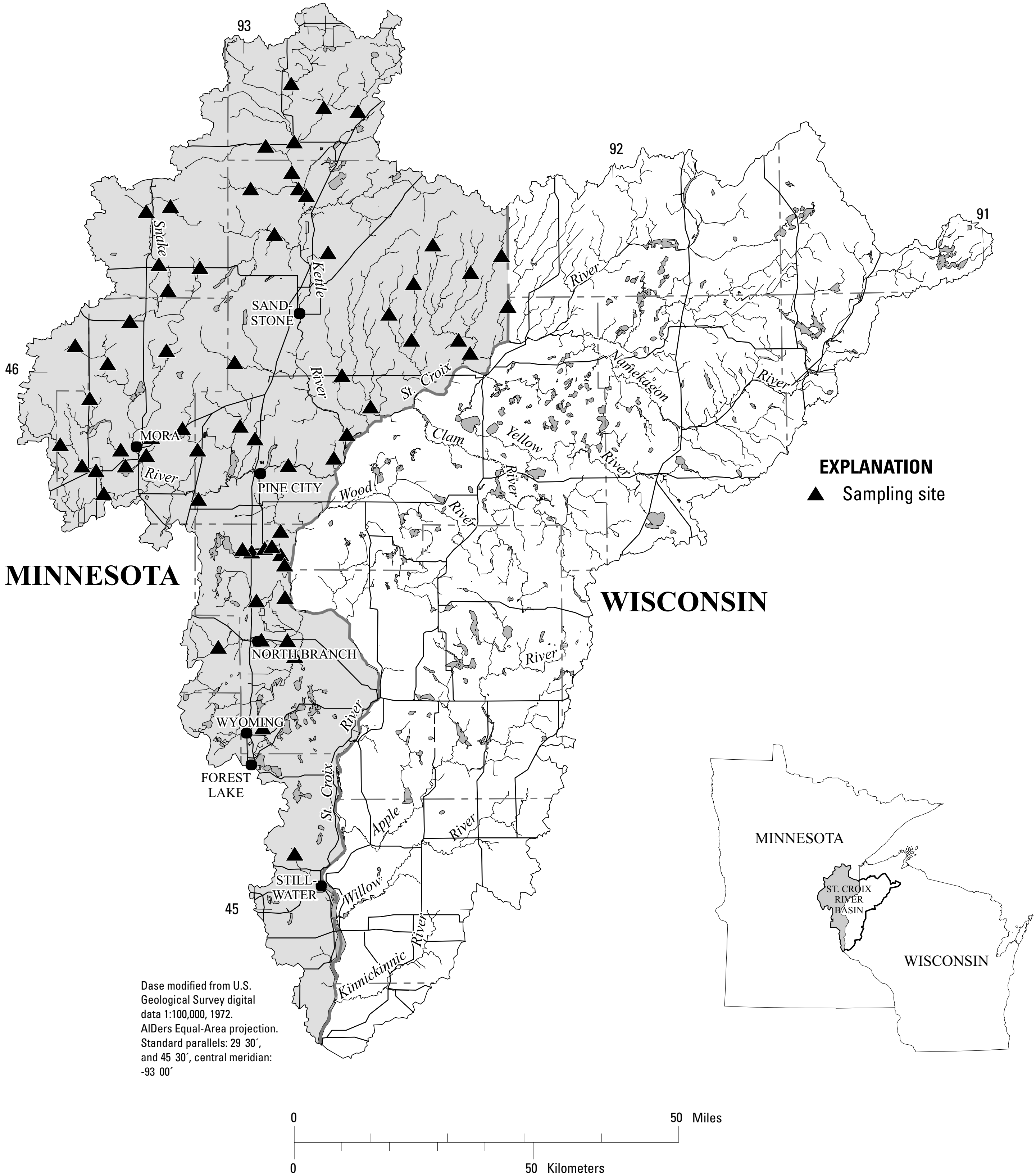

Figure 1. Location of the St. Croix River Basin and sampling sites in Minnesota.

Table 1. Habitat variables with transformations and variable abbreviations.

[Variables with an abbreviation were use in the analysis. Definitions of variables are given in appendix A.]

Classification groups and variables	Transformation	Abbreviation
Hydrology		
drainage area	ln (x)	lndrainarea
mean annual runoff	none	runoff
percent of basin with pervious soils	ln (x+1)	lnperv1
storage ratio	sqrt (x)	sqrtstorage
Geomorphology:		
sinuosity	ln (x-1)	lnsinu
gradient	ln (sqrt (x))	lnrtgrad
riffles per length of stream [a]	ln (x+1)	lnriffs/1000
pools per length of stream [a]	ln (x+1)	lnpools/1000
runs per length of stream [a]	ln (x+1)	lnruns/1000
bends per length of stream [a]		
mean width	sqrt (sqrt x)	widthrtrt
mean depth	none	meandepth
coefficient of variation of depth	sqrt (x)	cvdepthrt
erosion frequency		
Instream Habitat:		
number of log jams		
mean percent of algae		
mean percentage of macrophytes		
mean percent of over hanging vegetation		
mean percent of under cut banks		
frequency of over hanging vegetation		
frequency of under cut banks		
mean percent of woody debris	none	woody
mean percent of boulders	ln (x+1)	lnboulder
frequency of woody cover		
frequency of boulders		
frequency of submerged macrophyte cover		
frequency of emergent macrophyte cover	.	
Substrate:		
frequency of bedrock		
frequency of boulders		
frequency of cobble/rubble	none	cobble
frequency of gravel	none	gravel
frequency of sand	sqrt (x)	rtsand
frequency of silt		
frequency of clay		
frequency of detritus		
sum of small particle frequencies	sqrt(arcsin (x/100))	rtfines
mean depth of fines	ln (x)	lnfines
mean embeddedness		
Riparian Zone/Land Use:		
tree canopy (sum of four densiometer readings).	sqrt (x)	rtshade
agricultural within 100 m	sqrt (%)	rtag100
urban within 100 m	-1/(%+1)	turban100
forest within 100 m	none	forest100
wetlands within 100 m	sqrt (x)	rtwet100
water within 100 m	sqrt (x)	rtwater100
agriculture in basin	sqrt (x)	rtag
urban in basin	sqrt (sqrt x)	rurban
forest in basin	none	forest
wetland in basin	sqrt (x)	rtwet
water in basin		

[a] The number of geomorphic units or features was standardized for station length and ln transformed. The resultant variables were based on the ln of the number of units plus 1 (to account for zero values) per 305 meters (1000 feet) of stream.

poor water quality, poor habitat, habitat alteration (ditching, dredging) or a combination of these conditions. Therefore, the low IBI score was not necessarily a function of habitat.

Three data sets were created from the original sites that contained only normally distributed variables from streams with basins >25.9 km^2 and < 2,590 km^2. The smallest and largest streams were deleted from the analysis because the habitat was too variable in the smallest streams (either pristine or ditches), and the habitat in the largest rivers could not be adequately measured. The first group (Group A-development) had 25 sites while the second group (Group B-verification) had 17 sites. The third group (Group C-testing) had 26 sites. Some sites were sampled more than once. Replicate samples were treated as two different sets of data.

Core Habitiat Variables

The first objective was to identify the core habitat variables: the features that best describe physical habitat. This was accomplished by reducing the number of variables to a select few that are able to account for most of the variability in the habitat data set. Variable reduction is usually accomplished by principal components analysis (PCA)(for example, King and Jackson, 1999). All statistical procedures were accomplished with Systat 7.0 (SSPS, 1997).

Data for sites in groups A and B were analyzed with a PCA to identify those variables that accounted for the majority of the variability in each habitat data set. Conventional data reduction using PCA involves identifying the major factors in the data set represented by the PCA axes and defining surrogate variables for those factors. A correlation matrix is used to determine relations among variables, such that closely correlated variables group together on the PCA axes. Variables, or groups of related variables, that account for the most variability in the data occur at opposite ends of each factor (axis). The amount of variability associated with each factor (axis) is used to judge the number of factors needed to adequately describe the data set.

As part of the PCA output in Systat, a scree plot is generated. A scree plot has the number of factors (axes) on the x axis and the cumulative sum of the eigenvalues (variation explained by the factor or axis) on the y axis. The sum of the eigenvalues equals the number of axes that equals the total variability in the data set. Because each successive factor (axis) explains less and less of the total variation from the data set, there is a point beyond which adding additional factors contributes little to the explanation of variance. The scree plots for groups A and B data sets each indicated that 4 or 5 factors explained the majority of the variability in the data sets.

In groups A and B, the first three axes explain 58% and 65%, respectively, of the total variability in each data group. The core variables identified by the first two axes are almost the same for both data groups (fig. 2); on the first axis the core variable in group A was riffles per length of stream but in group B it was frequency of cobble/rubble substrate. Although the underlying factors were the same, there were differences in the core variables from the two data sets. Combining the core variables from both yields a set of variables (table 2) that are able to explain the majority of the variability in the habitat data set.

The 12 core variables represent the majority of the variation in groups A and B. The representation in each of the five classification groups is poor. Most of the variability is associated with the substrate and geomorphology classes. These would be considered to explain the majority of the variability and provide the most differentiation among sites.

Correlation of Core Habitat Variables with IBI

The second objective was to correlate the core habitat variables with IBI scores or other fish community statistics. Even though a habitat variable is very useful in explaining variability among streams, that does not necessarily mean it is important or correlated to the fish community. Therefore, it was necessary to determine which of the core habitat variables were correlated to IBI scores or fish community composition. A regression model of habitat and IBI scores was developed to identify the best set of core habitat variables to use in the habitat index.

The variables identified by PCA were used in a stepwise multiple regression to determine the best set of core habitat variables to explain as much of the variability in the fish community data as possible. Once the regression model was constructed, the data set containing the verification sites was used to verify variable selection by comparison of observed and estimated fish community statistics. Finally, testing of the regression model consisted of determining how well the model estimated the fish community statistics at the other (non-reference) sites. The quality of the model can be determined by examination of three aspects of the results: (1) The mean of the difference between the observed and estimated values should be close to zero; (2) The standard error of the estimate should be close to zero; (3) The observed and estimated values should correlate highly. A graph of the correlation of the observed to the estimated IBI values should have a y intercept of zero, and a slope of 1.

The core habitat variables (table 2) and group A data produced the following results (with appropriately transformed and normal data, table 1):

IBI = 36.25 + 2.0 (lndrainarea) + 5.95 (lnpools/1000) –1.011 (rtwet100) – 0.22 (rtshade)

The r^2 = 0.623 and the standard error of the estimate was 3.8. The correlation was highly significant ($p<0.0001$). This would seem to be a good model. However, the application of the equation to the data from group B gave these results: (1) The mean difference between the estimated IBI and the observed IBI was –3.3; (2) The standard error of the estimate was 7.2; and (3) There was no significant correlation between observed and estimated IBI values. The r^2 was 0.004. As an alternative approach, species richness was used.

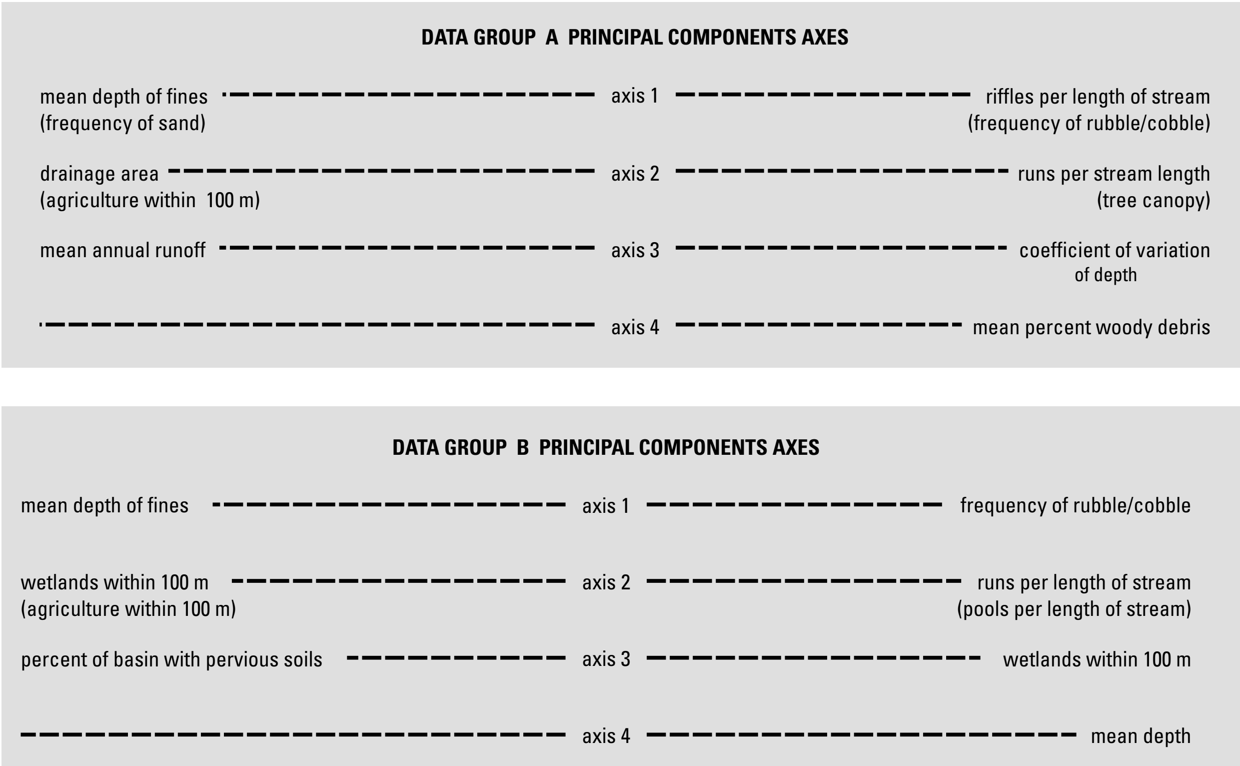

Figure 2. Schematic representation of principal components axes and important variables for site groups A and B. (The variables with the largest positive and negative loadings are indicated (negative on the left, positive on the right); secondary variables in parentheses.)

Table 2. Core Habitat variables identified by Principal Component Analysis.

[Definitions of variables are given in Appendix A]

Classification group	Variable
Hydrology	drainage area, mean annual runoff, percent of basin with pervious soils
Geomorphology	riffles per length of stream runs per length of stream coefficient of variation of depth mean depth
Substrate	frequency of cobble or rubble mean depth of fines
Instream habitat	tree canopy mean percent of woody debris
Riparian zone/land use	wetlands within 100 m

Correlation of Core Habitat Variables with Species Richness

The same PCA and multiple regression approach was used with species richness replacing IBI scores. Species richness may be more precisely replicated than IBI score, and species richness was highly correlated with IBI score (r^2=0.6).

The forward stepwise multiple regression of the core habitat variables (table 2) determined this model using data from group A:

Species Richness = -3.94 + 3.725 (lndrainarea) + 4.96 (lnpools/1000) + 0.17 (woody) – 1.07 (rtwet 100)

The r^2 was 0.78, the regression was highly significant, $p<0.0001$. When the model was applied to the data from group B, the mean of the differences between the observed and estimated species richness values was –1.04, which seems an acceptable value close to zero. However, the standard error of the estimate (5.1) was relatively high. The correlation between the observed and estimated species richness values was better than the correlations with IBI score (r^2 = 0.058); however, the results were not significant ($p>0.1$).

The results are analogous to the results achieved with the IBI scores. The linear regression model of habitat was not able to consistently estimate either IBI scores or species richness. The correlations that were generated for individual data sets were good. However, the linear regression model developed from one data set did not adequately describe another data set.

Concurrence Analysis with PCA

A recent article by King and Jackson (1999) describes an alternative and perhaps statistically more rigorous approach to variable reduction and the identification of core variables. They demonstrate a procedure using PCA to extract the most variability with the fewest variables. The procedure is based on using a "broken stick" model and the results of comparisons of methods made by Jolliffe (1972). It involves using the one variable with the highest loading from each of the first x number of axes as the core variables, where x is one-third the number of samples (Grossman and others, 1991). So, in the case of group A with 26 sites, variable reduction has the goal of determining 8 core variables or less.

Using this procedure, which is referred to as B4 by Jolliffe (1972), allows for confirming the variable selection process that was done using the previous core variable identification method. There is a high level of concurrence (agreement) between the two PCA analyses (table 3). Based on conventional and B4 methods together, there are 17 variables (table 4) that are the most important core variables to measure during habitat quantification or monitoring in the St. Croix River Basin.

Habitat Index

The third objective was the development of a basin-specific habitat index. Although IBI scores and species richness could not be fit to a correlation model of habitat quality, an index of habitat quality can be developed using the core variables. The habitat analysis identified 17 core variables (table 4); however, some of the variables were not used in the index either to reduce redundancy within the classification groups (pools per length of stream, percent sand, percent gravel, and urban land use), or to increase the ease of data aggregation (percent of basin with pervious soils). The final index includes 12 variables (table 5).

The index rates each habitat variable relative to the mean values in the data set and assigns a plus or minus to each factor. Each variable is adjusted to insure a plus sign corresponds to increased habitat quality and a minus sign to decreased habitat quality as derived from the St. Croix River Basin data relative to IBI scores and species richness. For example, high numbers of riffles receive a plus, while high numbers of runs receive a minus. To assign a plus or minus to the variable, any value exceeding the mean by about 5 percent receives a plus. Variables with values about 5 percent less than the mean receive a minus. Comparison factors that are similar to the mean (within about 5 percent of the mean) are not rated. The net sum of the pluses and minuses produces the numerical value of the index, which ranges from –12 (poorest habitat) to +12 (best habitat).

Verification and testing of the index follows a procedure similar to that used for the regression models. The index values are generated for each site (in this case development and verification data sets are used together) and then correlated with both IBI scores and species richness.

The regression of the combined data sets (groups A and B) with IBI scores produced a significant correlation (p=0.028). The significance may be due more to the number of observations (n=47) than the relation (a function of the number of degrees of freedom in the statistical test); however, the correlation was positive and the correlation coefficient was r=0.32.

The group C test data set contained 31 sites. Only 13 sites, however, had IBI scores. The sites sampled in 1998 have not yet

Table 3. Comparisons of the variables determined by conventional principal components analysis of axes and the B4 selection method (Jolliffe 1972).

[Definitions of variables are given in appendix A.]

Data Set	Conventional method	B4 method
Group A	mean depth of fines	riffles per length of stream
	riffles per length of stream	drainage area
	drainage area	mean annual runoff
	runs per length of stream	mean percent of woody debris
	mean annual runoff	forest within 100 m
	coefficient of variation of depth	storage ratio
	mean percent of woody debris	
Group B	mean depth of fines	mean depth of fines
	frequency of cobble substrate	runs per length of stream
	wetlands within 100 m	percent of basin with pervious soils
	runs per length of stream	mean depth
	percent of basin with pervious soils	frequency of gravel
	mean depth	mean annual runoff

Table 4. Habitat variables identified by two Principal Components Analysis methods listed by classification group.

[Definitions of variables are given in appendix A.]

Classification group	Variable
Hydrology	drainage area, mean annual runoff, storage ratio percent of basin with pervious soils
Geomorphology	riffles per length of stream runs per length of stream pools per length of stream
Instream habitat	mean percent of woody debris coefficient of variation of depth tree canopy
Substrate	frequency of cobble/rubble mean depth of fines frequency of sand frequency of gravel
Riparian zone/land use	forest within 100 m agriculture within 100 m urban with 100 m

had IBI scores determined. The correlation coefficients were very low and the regressions were not significant between the habitat index and IBI scores or species richness.

If the index does in fact reflect the quality of the habitat and is related to the IBI score, then the addition of the third data set to the first two should increase the resolution of the correlation because the range of conditions has been increased. No increase in the correlation coefficient would indicate that the index could not distinguish poor habitat sites from good habitat sites, using IBI scores as the measure of “good” and “poor”.

The regression of the habitat index and IBI scores for all 60 sites (fig. 3) improved the correlation. The correlation coefficient increased to 0.44, and the regression was highly significant ($p=0.0004$).

Two sites, an unnamed tributary and Brown’s Creek, had very low IBI scores and species richness but moderate habitat indices. The deletion of these two sites increased the correlation. The coefficient of determination increased ($r^2 = 0.25$), indicating about a 5 percent increase in the variance explained, and the standard error of the estimate decreased from 8.4 to 7.4.

The habitat index can be used in conjunction with the IBI to identify streams where low IBI scores may not be due to the quality of the habitat. The approximate relation is:

IBI Score = 46 + Habitat Index

An observed IBI score for the stream more than 15 points (2 standard errors) below the calculated value (as was the case with the unnamed tributary and Brown’s Creek), may be indicative of water-quality problems. The low IBI score may not be due to quantity or quality of habitat.

Discussion

The analysis went through numerous steps. The original procedure did not produce and index. It may be that the streams were too similar for the PCA/multiple regression program to be successful. The method that did lead to the index was a concurrence method; whereby, the data sets were examined for similarities. The similar features were used to develop the index. The original approach may be appropriate in another basin. There is no way, however, to determine beforehand which habitat analysis method to use.

Our planned analytical approach proved to be inadequate. There was no correlation between the observed and estimated IBI scores or species richness in the verification data set. These results indicate that the regression model of core habitat features and IBI scores or species richness cannot be used. Is habitat irrelevant to the quality of the fish community? How can there be no correlation between IBI scores and habitat or species richness?

Table 5. Habitat variables with means and correlation to IBI scores.

[Definitions and units of variables are given in appendix A.

Habitat Variable	Correlation to IBI score or species richness	Mean value
Hydrology		
drainage area	positive	130
mean annual runoff	positive	9.4
storage ratio	negative	30
Geomorphology		
riffles per length of stream	positive	10
runs per length of stream	positive	16
Instream habitat		
percent total cover[a]	positive	45
tree canopy (total densiometer)	positive	210
coefficient variation of depth	positive	50
Substrate		
frequency of cobble/rubble	positive	25
mean depth fines	negative	0.6
Riparian zone/land use		
forest within 100 m	positive	40
agriculture within 100 m	negative	20

[a] Total cover is the sum of percentages of boulders, woody debris, over hangs, undercuts, and macrophytes.

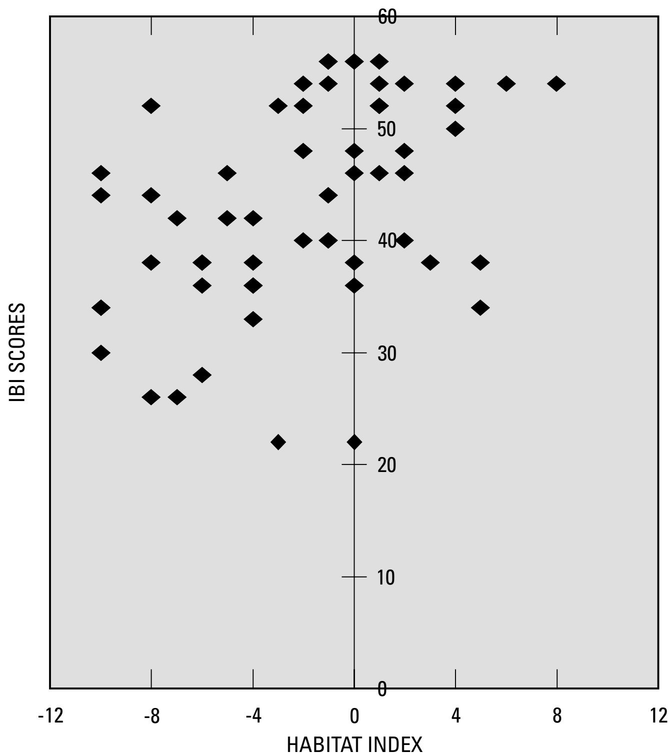

Figure 3. Relation between the habitat index and the IBI scores for the St. Croix River Basin for all sites sampled.

There are at least two different answers. The first is that IBI scores have poor statistical properties. The second is that not enough, or not the correct, habitat variables were used.

IBI scores may not have great precision (reproducibility) and therefore may be poor variables for regression analysis. The confidence interval on an IBI score can be 12 points, although most confidence intervals are 6 points (Fore and others, 1994). Assuming a conservative confidence interval of 6 points, every point could range three points to the left or right (fig. 4). If the estimated score (estimated from the habitat variables) had similar confidence limits, it too could shift the data point a similar distance in the other directions (up or down). The arrows in figure 4 indicate the range of possible locations for the data point in the center. Therefore, the location of the data point may not be precisely determined. Normally, one characteristic of the independent variable (observed IBI score in this instance) is that it can be accurately measured; this may not be the case with IBI scores.

The range of the values of the data points used for model development further confounds the relation between observed and estimated scores. If the range used is only one-half the total range of possible IBI scores, as it is here (one of the selection criteria for sites for model development was an IBI score above 35 or 45 depending on drainage area), the relation between observed and estimated is obscured. Only one-half of the relation is under consideration. When the scale approximates the full range of potential IBI scores from 12 to 60, the effects of scale become more apparent (fig. 5). The 45-degree line indicates the correspondence line that would occur with perfect agreement between the observed and estimated IBI scores. If the full range of IBI scores had been used, then perhaps points at the lower end of the range of score values could have better defined the relation between observed and estimated scores.

The lack of resolution and correlation appears to be, at least partially, the result of the imprecise value of the IBI used for this analysis. An analysis of the statistical properties of the IBI indicated that the index is in fact variable and that at least 8.5 points are necessary to distinguish a difference between two sites (Fore and others, 1994). The same study also used power analysis to determine that 5 or 6 distinct scoring classes could be determined. Several earlier analyses of the IBI indicated that the mean value has a standard deviation of about 4 units (Angermeier and Karr, 1986). Therefore, using IBI score as an independent variable in a regression analysis may not be appropriate.

Shields and others (1995) found little correlation between IBI scores and habitat degradation in Mississippi streams. They attributed the lack of correlation to the temporal variability in IBI scores at degraded sites where they had sampled. They also indicated that the lack of reference sites may have affected the ability of the IBI to adequately incorporate a full gradient of habitat quality. This was not the case with the St. Croix River Basin data. The

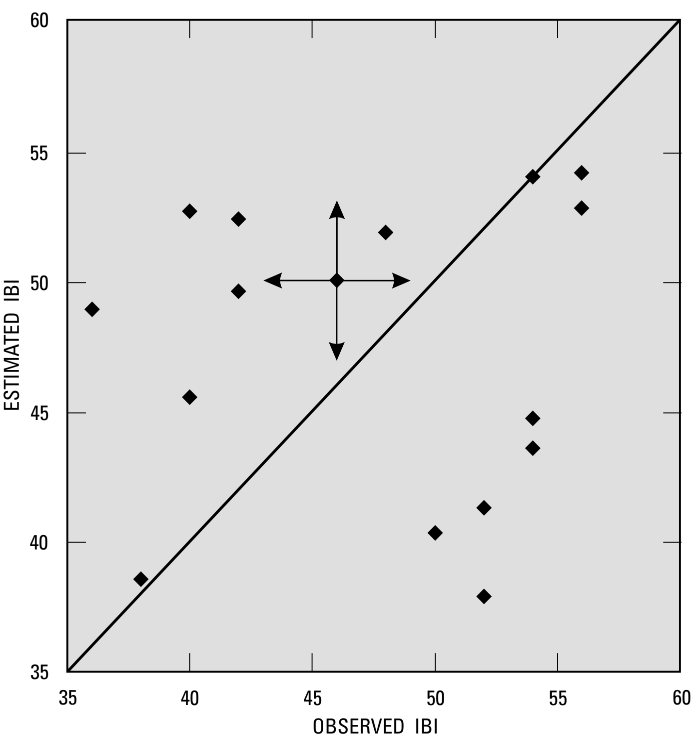

Figure 4. Observed and estimated IBI scores at sites with good habitat. The 45 degree line is the hypothetical perfect agreement between observed and estimated scores. Arrows indicate the potential range of IBI values for a single point.

sampled sites included almost pristine streams in forested settings at one end of the gradient, to channelized ditches in agricultural landscapes at the other end. A gradient of habitat quality that lacked chemical, landscape, or other sources of degradation might have produced a more distinct relation. The loss of resolution due to the presence of sources of degradation other than habitat is a real complicating factor. The relation between IBI and habitat is obscured as IBI score decreases because the IBI score responds to sources of degradation other than habitat quality. It may even be reasonable to conclude that streams that are subject to the greatest amount of habitat disruption are also subject to the greatest amount of chemical and landscape sources of degradation in urban areas and areas of agriculture and forestry. The precision of the IBI decreases with biotic integrity (Fore and others, 1994): the lower the IBI score, the wider the confidence interval. With other sources of degradation, the habitat and IBI relation would disintegrate at the low end, and the utility of the habitat index would decrease.

Although the habitat index is only able to explain about 20 percent of the variability in IBI scores, it does account for the majority of the variability in the habitat data. One difficulty with this analysis is that low IBI scores may not be strictly attributable to habitat quality. For example the two lowest IBI scores (fig. 5) came from two very small streams, an unnamed tributary and Brown's Creek (drainage areas 27.4 km^2 and 35.2 km^2, respectively). While both sites received the same IBI score of 22, the unnamed tributary had a habitat index of 0, and Brown's Creek had a habitat index of –3. The unnamed tributary contained 2 species, but Brown's Creek had 5. It certainly is possible that factors other than habitat could be contributing to the variance. In fact, when these two sites are deleted from the analysis the results were significantly changed. Some additional testing would be necessary to determine the behavior of the index over a range of conditions and how it behaves mathematically and statistically.

The analytical procedure that led to the index may not have included the proper variables to define the habitat and IBI relation. A number of the initial variables could not be used because they were almost categorical. Many of the variables had a large percentage of zero values and could not be successfully transformed to fit a normal distribution. While these variables could not be used in this analysis, they certainly contain relevant information. Variables included in the analysis however, did represent the major habitat variable groups (hydrology, geomorphology, instream habitat, riparian zone, and substrates that have been used in other habitat indices (Stauffer and Goldstein, 1997). When about 60 percent of the variability in habitat and as 80 percent of the variability in species richness can be explained with the variables identified from the original habitat data collection, no new habitat variables would seem needed.

A greater change occurred to IBI scores as habitat quality decreased. The range of estimated IBI scores was greater with habitat index values that were negative than habitat scores that were positive. When IBI scores from average sites were compared to IBI scores from high quality sites, there was not a great deal of difference, the scores were similar. However, when IBI scores from average habitat sites were compared to sites with low habitat scores, the IBI values decreased. It appears that "good" habitat is

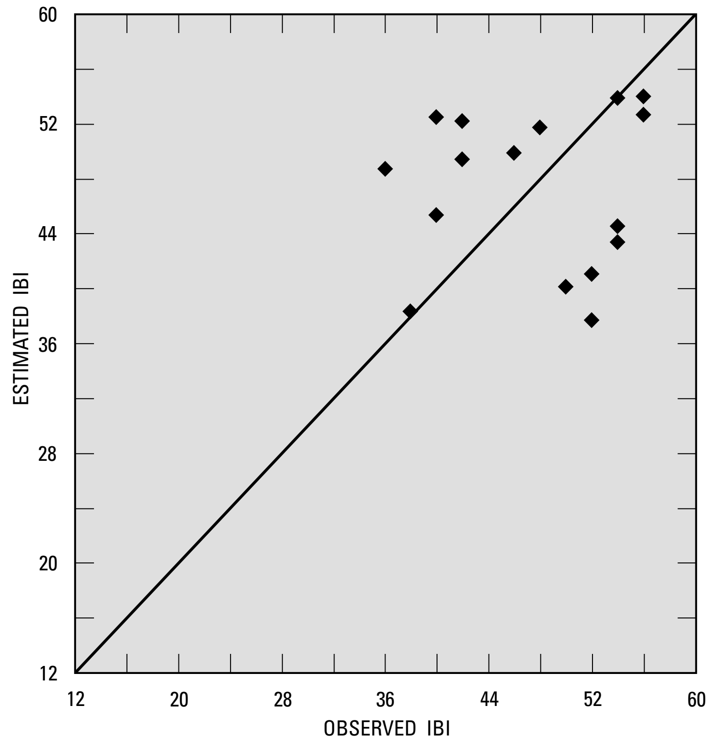

Figure 5. Observed and estimated IBI scores at sites with good habitat throughout the full range of possible scores. (The 45 degree line is the hypothetical perfect agreement between observed and estimated scores.)

an amalgamation of conditions. The conditions can be better, but the community response is minimal and difficult to determine. Conversely, when the habitat conditions degrade, the effect is more pronounced and more readily reflected in the IBI scores.

The application of the habitat index to field work would allow a reduced number of variables to be measured in the field and therefore increase the cost efficiency of the habitat data collection, while maintaining sufficient information to evaluate the biocriteria for a site.

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Appendix

Habitat variables by classification group.

Hydrology (basin-level variables):

1. Size of the drainage basin in square miles
2. Mean annual runoff in inches per square mile per year

Even though sampling should have occurred during stable low flow conditions, that was not always the case. The historical hydrologic conditions can have a profound effect on the fish community of a stream (Harrel and others, 1967; Matthews, 1986; Pearson and others, 1992). Hydrologic history was quantified for each major subbasin with the mean annual runoff statistic that was used for all the sites within the same subbasin. Although this variable ignores evapotranspiration (which may be significant in forested or highly agricultural basins), it still gave an order-of-magnitude approximation of the total amount of water in the stream during the year prior to sampling.

3. Percent of the basin area with pervious soils (derived from the U.S. Department of Agriculture, 1991, STASTGO data base). The type of soil in the basin may be significant in affecting the quantity of water in a stream and how rapidly runoff reaches a stream. The soil hydrologic group, which is a measure of the runoff potential, was retrieved from the U.S. Department of Agriculture's STATSGO data base, and the proportion of the basin with pervious soils was calculated for the basin upstream of each site (Stauffer and others, 2000).

4. Storage ratio the proportion of the total basin area in water or wetland

Geomorphology (reach-level variables):

1. Sinuosity (segment level)
2. Gradient in feet per mile (segment level)
3. Total number of riffles
4. Total number of pools
5. Total number of runs
6. Total number of bends
7. Mean channel width, based on 5 points on each of 13 transects, in feet
8. Mean channel depth, based on 5 points on each of 13 transects, in feet
9. Coefficient of variability of depth
10. Erosion frequency, the number of times erosion was observed at the two ends of each transect divided by the total number of observations

Instream habitat (developed into reach-level variables from transect data):

1. Number of log jams in the reach
2. Mean percent of algae observed at a point on a transect, based on 5 points on each of 13 transects
3. Mean percent of macrophytes observed at a point on a transect, based on 5 points on each of 13 transects
4. Mean percent of overhanging vegetation, based on the amount (percent) of overhanging vegetation observed on both sides of 13 transects
5. Mean percent of undercut banks, based on the amount (percent) of undercut banks observed on both sides of 13 transects
6. Frequency of overhanging vegetation, based on the number of observations of overhanging vegetation at all the transects
7. Frequency of undercut banks, based on the number of observation of undercut banks at all the transects
8. Mean percent of woody cover, based on the amount (percent) of woody cover at each transect
9. Mean percent of boulders, based on the amount (percent) of boulders at each transect
10. Frequency of woody cover at all the transects
11. Frequency of boulders at all the transects
12. Frequency of submerged macrophyte cover at all the transects
13. Frequency of emergent macrophyte cover at all the transects

Substrate (converted to frequency of occurrence for the reach; each point on each transect was treated as one of the total number of observations, 5 points per transect).

1. Frequency of each substrate type (bedrock, boulders, cobble/rubble, gravel, sand, silt, clay, and detritus)
2. Mean depth of fines
3. Mean embeddedness, based on quartiles
4. Small particles, the sum of the frequencies of sand, silt, clay, and detritus

Riparian zone/land use (land use was classified as forest, agriculture, urban, wetland, water, or other):

1. Tree canopy (total amount of shade, based on the sum of all four densiometer readings)
2. Percent land use within 100 meters of the stream
3. Percent land use in the basin